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# A Statistical Evaluation and Comparison of VISSR Atmospheric Sounder (VAS) Data and Corresponding Rawinsonde Measurements

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TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM

# A STATISTICAL EVALUATION AND COMPARISON OF VISSR ATMOSPHERIC SOUNDER (VAS) DATA AND CORRESPONDING RAWINSONDE MEASUREMENTS

## I. INTRODUCTION

In the fall of 1980, the first VISSR Atmospheric Sounder (VAS) was launched into geostationary orbit onboard the GOES-4 spacecraft bringing new remote sounding capabilities into existence. Since then, two more VAS instruments have been launched with the last two being operational at this writing. VAS measures radiation emitted by the atmosphere in 12 infrared channels and is capable of collecting sounding quality radiances at frequent time intervals (References 1, 2, and 3 give instrument description and operating modes). These radiances can be used to produce vertical profiles of temperature and moisture in the cloud-free environment by inverting the radiative transfer equation.

The usefulness of multispectral imagery and sounding products has been demonstrated recently by several groups [4-7] without much regard to the accuracy and representativeness of these products in describing mesoscale atmospheric features. This is mainly because of the lack of verifying measurements. In the spring of 1982, Marshall Space Flight Center conducted an experiment aimed at collecting rawinsonde measurements of similar resolution to those available from VAS. This report presents some results of a comparison study between VAS soundings produced using various retrieval algorithms and corresponding ground truth rawinsonde data from the AVE/VAS experiment.

## II. DATA AND PROCEDURES

### A. Data

Two basic types of data were used in the study; namely, rawinsonde and VAS sounding data for the 6-7 March 1982 experiment day. Details of this and other experiment periods in the spring of 1982 may be found in References 8 and 9. The rawinsonde data used in the evaluation consisted of the basic thermodynamic parameters at 50 mb increments from the surface up to 100 mb. The rawinsonde locations of interest are shown in Figure 1. The spacing of these sites is roughly 125 km over central Texas providing detailed mesoscale resolution of atmospheric features. The nominal release times of the rawinsonde data were 1200, 1500, 1800, and 2100 GMT on 6 March 1982 and 0000 GMT on 7 March 1982.

The VAS sounding data available for this period consisted of three data sets. The first satellite data set contained soundings produced using a scheme similar to the one used by Smith [10]. The scheme is a physical one, where an iterative solution is employed and LFM model output is used as first guess information. These soundings will be referred to as "physical" retrievals. The second data set is similar to the previous one except an analytic solution is employed after the iterative physical retrievals are obtained in order to provide more vertical structure to the satellite profiles [4]. These soundings will be called "modified physical" retrievals.

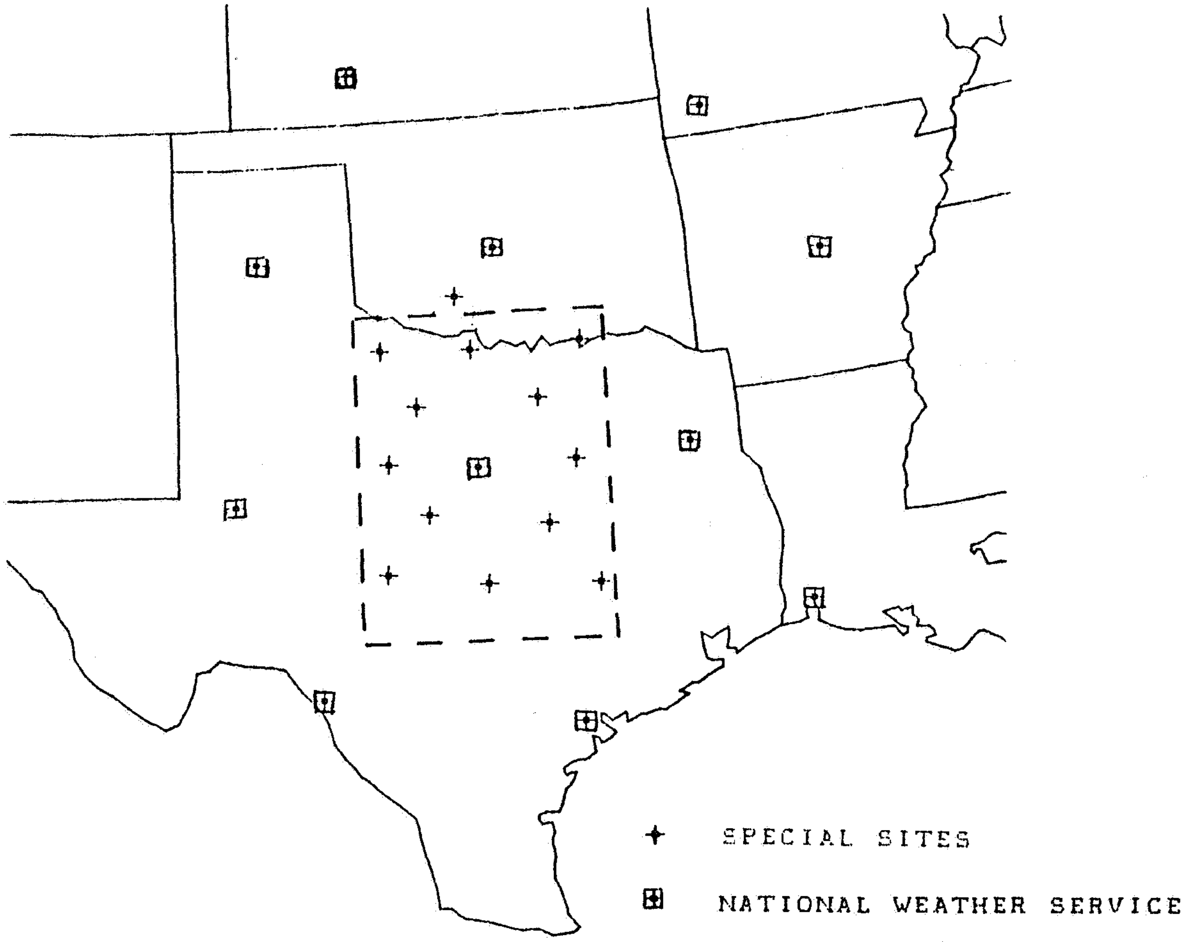


Figure 1. Rawinsonde sites used in the gridded analysis on 6 March 1982. The grid area (10 x 13) for both the satellite and rawinsonde data is located in central Texas (dashed box).

The third set of VAS soundings was produced using a linear regression scheme as described by Lee, et al. [11]. This method uses a local rawinsonde data set to determine statistical relationships between the radiance measurements and the structure of the atmosphere. These relationships are then applied to the observed radiance measurements to derive temperature and moisture profiles. This data set will be denoted as "regression" soundings. In all three data sets, soundings had a horizontal spacing of approximately 75 to 100 km spacing over the entire cloud-free region of Texas, Oklahoma, and surrounding states. This spacing (resolution) should not be confused with the area over which radiances are averaged before the production of satellite retrievals which may vary from 1000 to 6000 km$^2$. The location of the soundings varied with time due to the extent and variation of the cloud cover.

### B. Data Handling Procedures

Rawinsonde and satellite soundings are rarely co-located in space nor taken at the same time thus making comparisons between them difficult to interpret. To overcome this problem, special procedures were used to make these data sets more consistent. First, the ground truth rawinsonde data were adjusted to a common release time (10 min. after the beginning satellite scan time) using a scheme described by Fuelberg and Jedlovec [12]. The new rawinsonde times in the study are 1100, 1445, 1745, 2045, and 2345 GMT 6 March 1982. The rawinsonde and satellite data were both objectively analyzed to a uniform grid with the balloon position (radiosonde) being recalculated at every level in the vertical. This procedure eliminated any spatial discrepancies since the same grid was used for all data sets (Fig. 1). The same objective analysis scheme weighting parameters were utilized with all the data sets so that the potential for detail in the gridded fields was similar in each case.

The procedures followed in this evaluation and described above have provided three sets of satellite data at constant pressure surfaces from the surface to 100 mb. Utilizing identically gridded rawinsonde data, mean differences, standard deviations of the differences, and root-mean-square differences between the rawinsonde and each satellite grid were calculated. In Section IV, mean differences, along with analyzed fields and vertical profiles of rawinsonde and satellite data will be presented.

## III. SYNOPTIC CONDITIONS

The selection of experiment days for the simultaneous collection of rawinsonde and satellite data was based on weather conditions forecasted for a particular period. The 6-7 March 1982 case was to be used for extensive ground truth comparisons because of a large region of predominately cloud-free skies over the special network region. Figure 2 presents the surface and 500 mb analysis at 1100 GMT 6 March 1982, the start of the experiment. At the surface (Fig. 2a), a low pressure center was present along the Gulf Coast with a stationary front extending southwestward into Mexico. Behind this front, a shallow high pressure area was centered over western Oklahoma. To the north, a cold front, extending from a low up in Canada, was pushing south through the upper plain states. The thermal gradient over the central portion of the region was quite strong with a 15°C gradient over Texas and a similar one over the central plains. The regional network was predominantly cloud-free (not shown) except for low clouds in east Texas and convective clouds with thunderstorm activity over Louisiana, Arkansas, and Missouri. Several inches of snow were present on the ground in portions of Oklahoma and west Texas but melted during the afternoon hours.

At 500 mb, a large amplitude trough was positioned over the regional network in a northeast-southwest orientation (Fig. 2b). This trough is well defined by the height and wind shear field. A very narrow jet streak was present in the southern portion of the region with maximum winds exceeding 35 ms at Stephenville and Tucson. This trough propogated eastward with time moving through central Texas by 0000 GMT 7 March 1982.

## IV. RESULTS

### A. Constant Pressure Comparisons

Figure 3 displays the mean temperature difference between the rawinsonde and satellite data sets as a function of pressure and time. Since the rawinsonde is considered "ground truth" in the study, the satellite grid point values were subtracted from the rawinsonde values ($T_{RAO} - T_{SAT}$). Several main features are

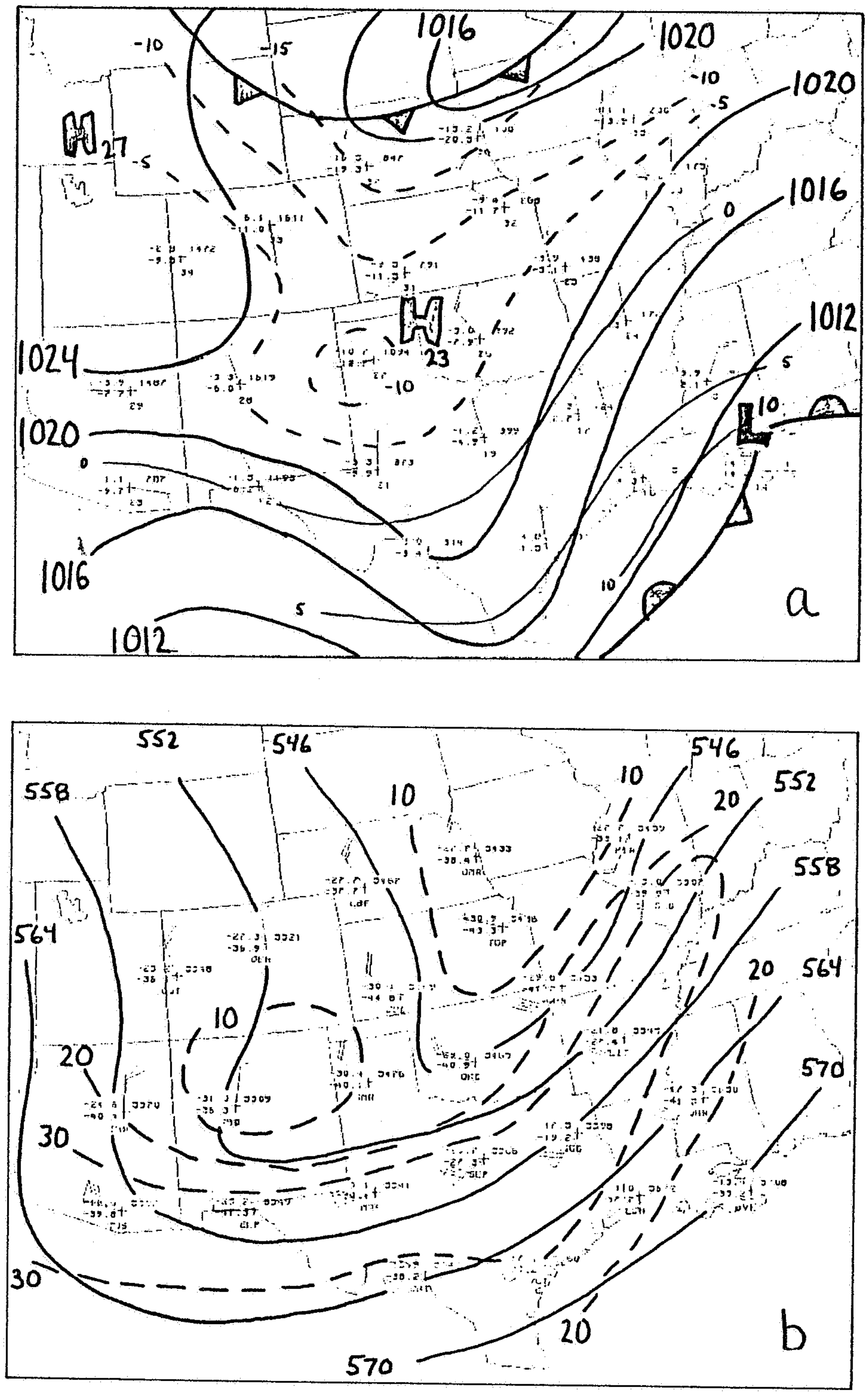


Figure 2. Surface analysis (a) and 500 mb pressure chart (b) at 1100 GMT 6 March 1982. For the surface map, pressure is in millibars and temperature is in °C. The 500 mb contours are in decameters with isotachs in $ms^{-1}$.

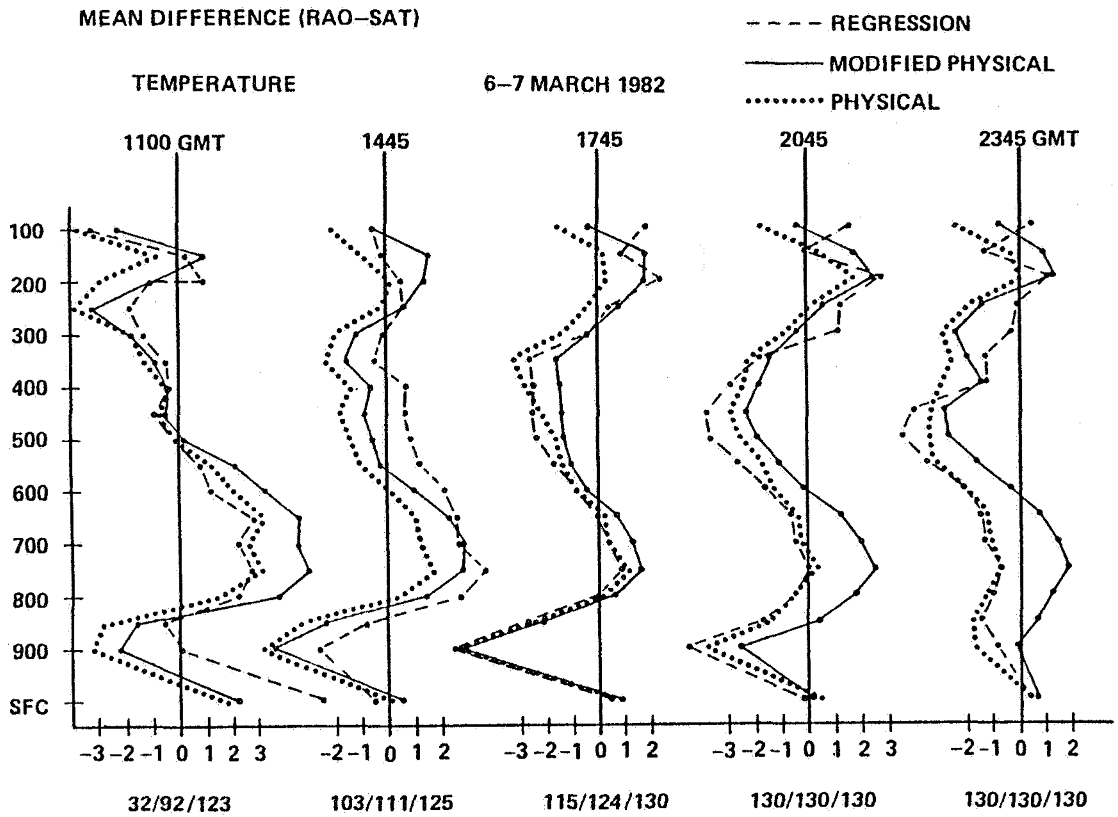


Figure 3. Mean temperature difference profiles as a function of pressure and time for each retrieval method. Units are in °C (horizontal axis). The numbers at the bottom are the number of grid points used for the regression, modified physical, and the physical schemes, respectively.

noticeable and common to all three satellite data sets. First, there is a low level warm bias ($T_{RAO} - T_{SAT} < 0$) in the satellite grids from the surface to about 800 mb. It ranges in magnitude from 3° to 5°C and is strongest at 1745 GMT. Above this level, there exists a cold bias up to around 600 mb which is present in all satellite data sets for the first three time periods. At the last two time periods, the cold bias gives way to a slight warm bias for the physical (dotted lines) and regression (dashed lines) sounding sets. The modified physical soundings (solid lines) maintain a cold bias at these times. Undoubtably, this pattern is directly related to the low level frontal inversion present over the analysis region (Fig. 4) which weakens (as a result of boundary layer heating) with time (not shown). There is a tendency for the biases to become smaller as the frontal inversion weakens. The inability of the VAS retrievals to capture this feature is a result of the broad weighting functions in the lower troposphere.

In the middle and upper troposphere, the temperature biases in the satellite soundings are not extremely large until 1745 GMT when biases of 2° to 5°C are present and persist through 2345 GMT. Again, all three satellite data sets show this bias with physical retrieval biases being smallest in this layer (600 to 300 mb). Above 300 mb there seems to be a compensating cold bias up to about 150 mb. This bias pattern is related to the lowering of the tropopause onto the frontal boundary at 1745 GMT creating a strong temperature inversion near 350 mb (Fig. 4). This inversion continues to lower, strengthens during the next two time periods and

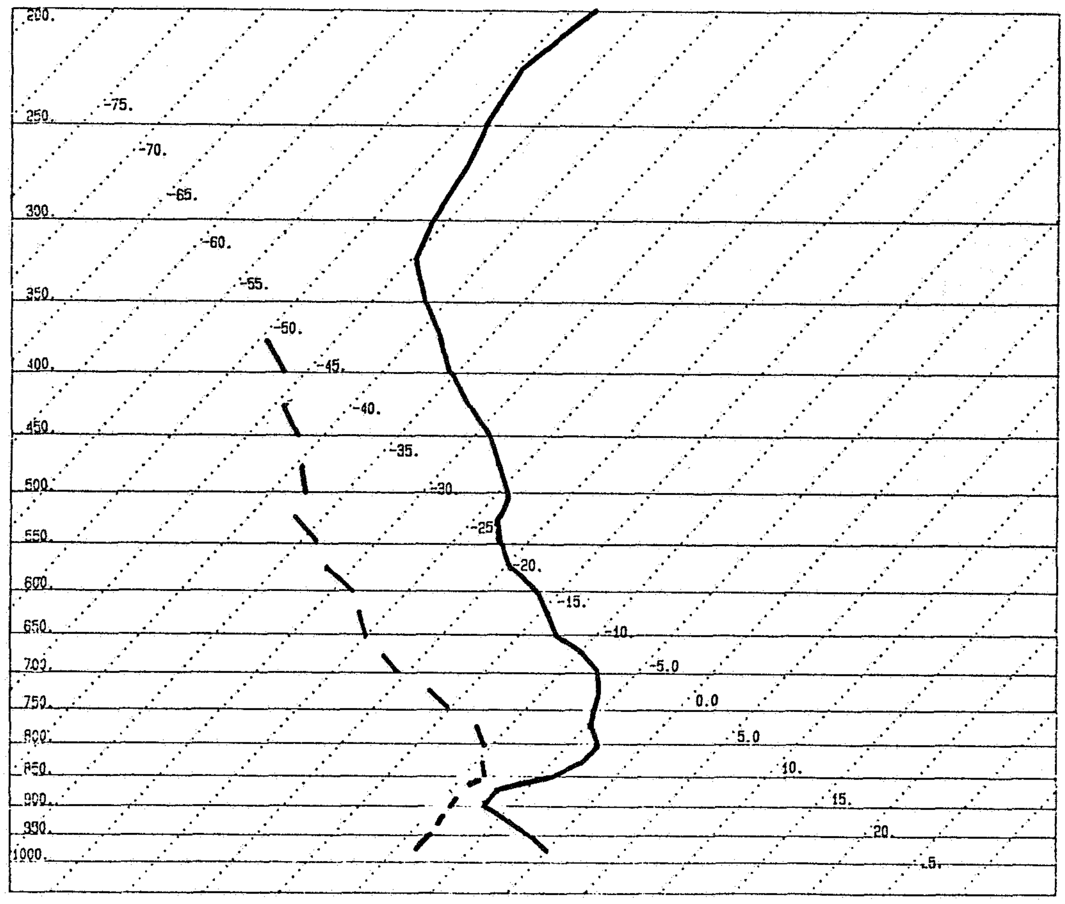


Figure 4. Skew-t diagram indicating the temperature (solid) and dewpoint temperature (dashed) profiles for Stephenville, Texas at 1745 GMT 6 March 1982.

the corresponding warm satellite biases get worse. Maximum values approach 6°C at 2345 GMT for the regression scheme (dashed line).

## B. Vertical Structure

In order to properly evaluate the vertical structure resolved with the VAS soundings, grid mean profiles of the satellite and rawinsonde data sets are presented in Fig. 5 for 2045 GMT 6 March. The rawinsonde profile (solid line) is somewhat smoother than normal since it is a grid mean profile but contains two major inversions (Fig. 4). All three satellite grid mean profiles at 2035 GMT indicate the biases previously discussed (Section IV.A) and mis-assign the levels of the inversions. This is due to the broad weighting functions and to the low signal-to-noise ratio of the radiance values in the upper levels.

The dewpoint profile indicates a rather dry environment with some residual moisture in the lower and upper levels. This structure is only grossly captured by the satellite soundings (as expected since there are only three moisture channels on VAS). The regression retrievals (dotted line) do a good job of representing the rawinsonde profile while the physical (dot-dashed line) and modified physical (dashed

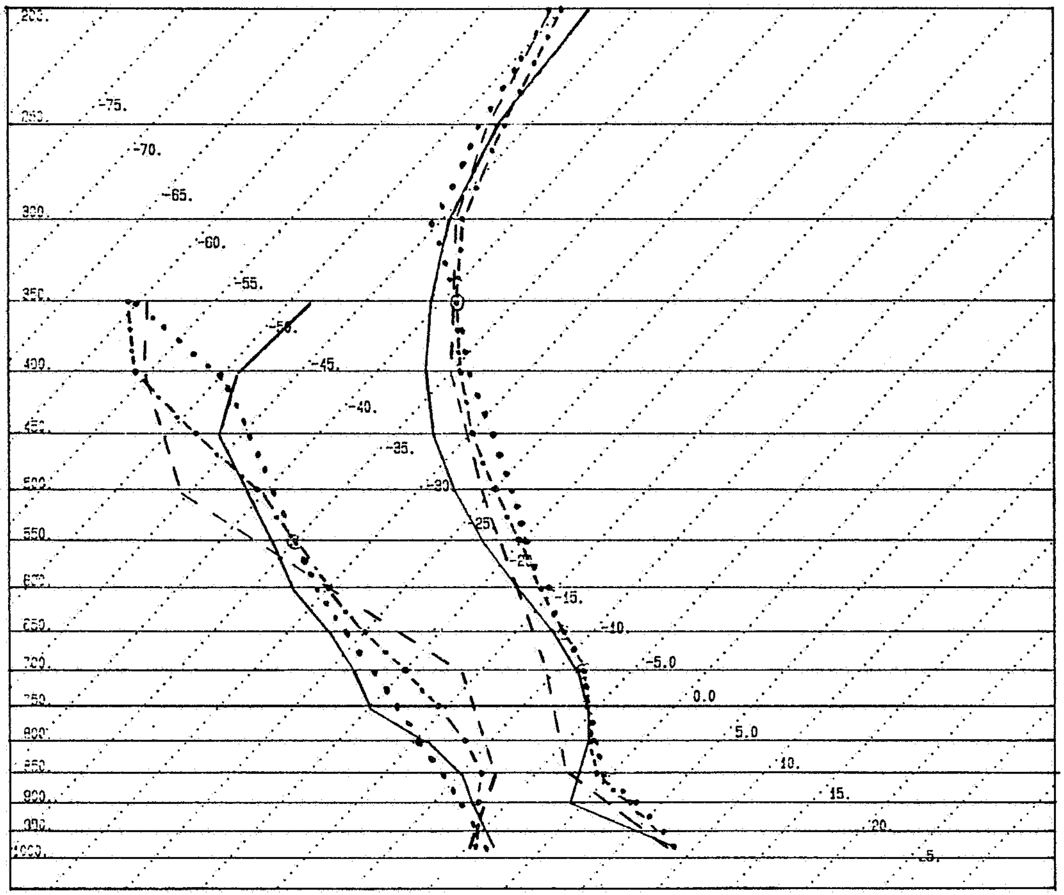


Figure 5. Grid mean Skew-t profiles of temperature and dewpoint temperature for the rawinsonde (solid), regression (dotted), physical (dash-dotted), and modified physical (dashed) data sets at 2045 GMT 6 March 1982.

line) schemes seem to over-estimate the low level moisture and under-estimate the upper level amounts. Moisture differences will be further evaluated in the next section.

## C. Derived Parameter Evaluations

Gridded fields of 500 mb geopotential height values derived from the temperature and moisture data are presented in Figure 6 at 2335 GMT. Biases discussed in the previous sections will influence the fields of geopotential height values, however, alternating levels of warm and cold biases (previously discussed) may cancel some accumulation of error in these derived fields. Figure 6a shows the rawinsonde height field over the special network. A strong gradient exists in the northeast-southwest direction on the order of 50 m. There is a small perturbation in this field making the gradient non-uniform. All three of the satellite derived height analyses capture some portion of the rawinsonde analysis. The physical sounding analysis (Fig. 6b) and the modified physical analysis (Fig. 6c) present a uniform gradient which is orientated more in the east-west direction than the rawinsonde grid. The regression analysis (Fig. 6d) presents a non-uniform field similar to the rawinsonde. In all three satellite cases, the magnitude of the gradient across the network is similar, however, absolute values indicate that the physical and modified physical schemes are roughly 10 m too low while the regression soundings are a similar amount

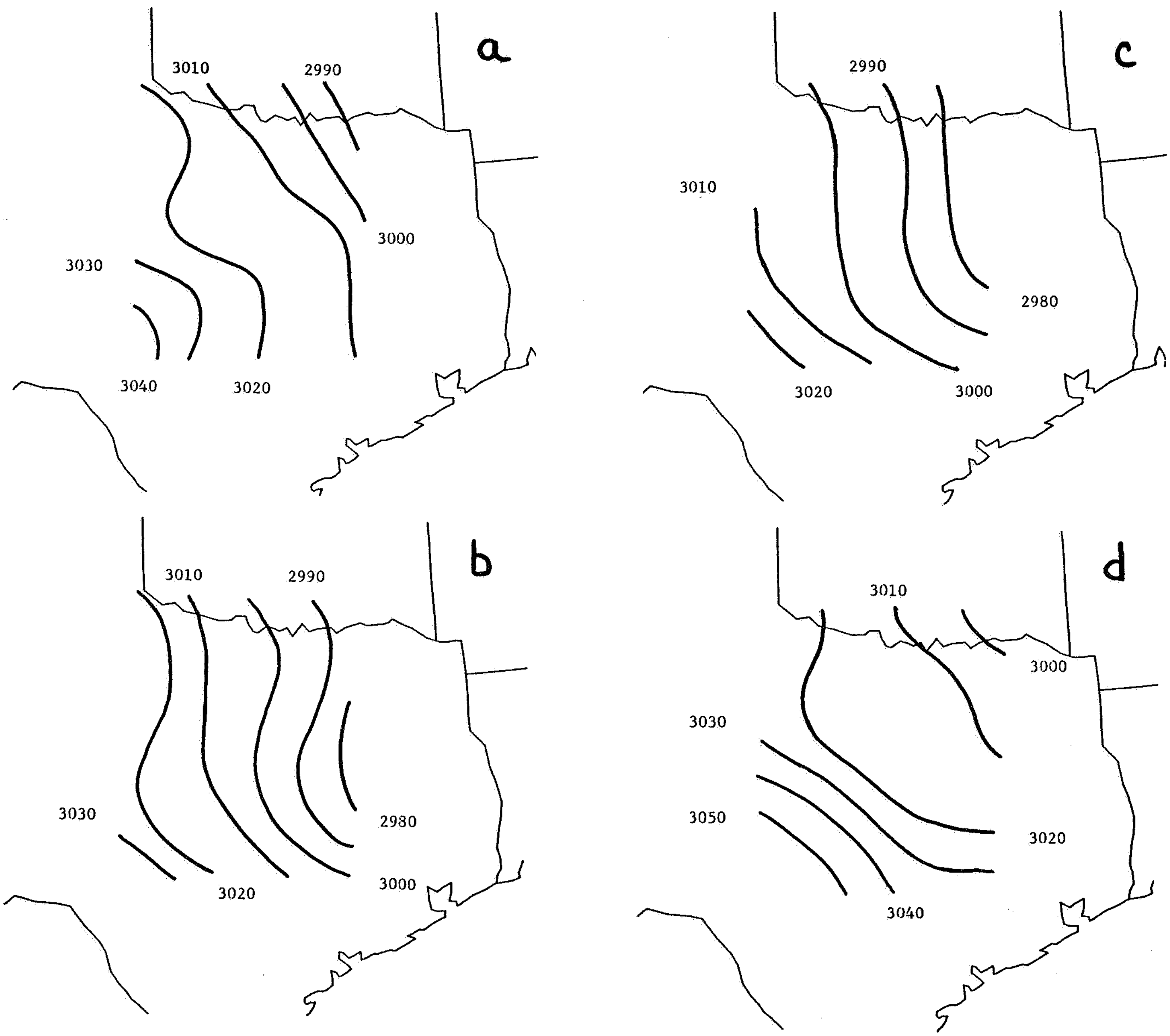


Figure 6. 500 mb height analyses over the mesoscale grid region at 2345 GMT 6 March 1982 for the rawinsonde (a), physical (b), modified physical (c), and the regression (d) retrievals. Contours are in meters.

too high. This can be traced back to the temperature biases (Fig. 3). These satellite analyses are definitely quite good. Admittedly, these analyses represent the "cream of the crop" so to speak. The accuracy of the satellite analyses indicated here does not always remain consistent with time or in space however.

Figure 7 indicates the mean precipitable water differences as a function of time over the special network. As was pointed out with the dewpoint values (Section IV.B), the physical soundings (dotted line) and the modified physical soundings (solid line) are too moist, with mean precipitable water differences approaching 3 mm at 1445 and 1745 GMT, respectively. Although this does not seem excessive it represents over 30 percent of the total precipitable water in the column. The regression soundings have relatively small difference values except at 1445 GMT when they approach 2.0 mm. Although this is quite good, horizontal fields of this quantity (not shown) indicate very little gradient when the rawinsonde values indicate there should be one.

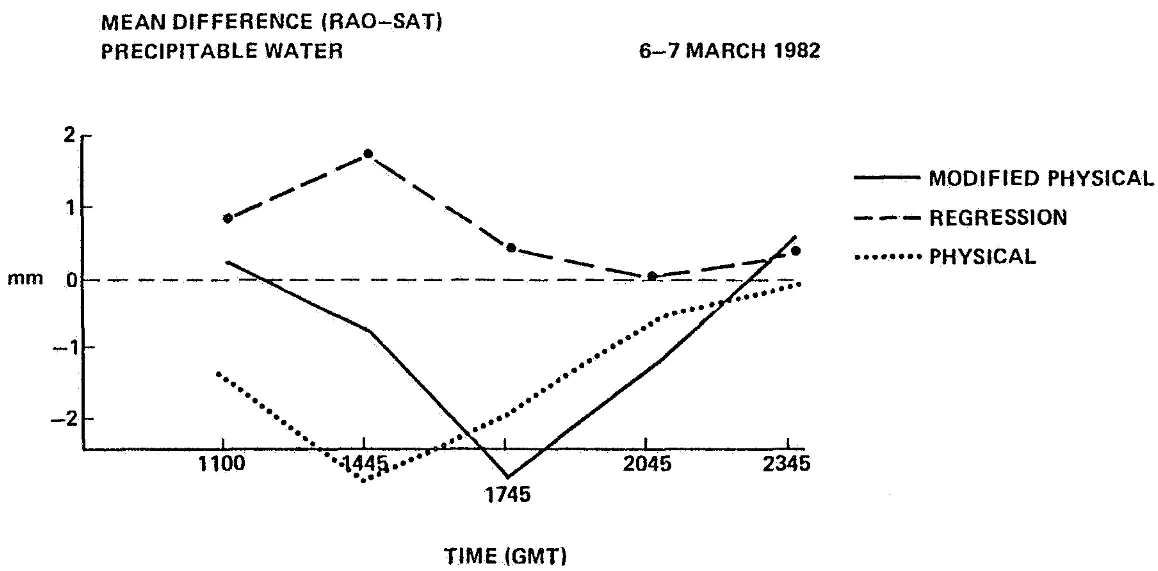


Figure 7. Mean precipitable water difference as a function of time for the modified physical, regression, and the physical retrieval schemes. Units are in millimeters.

## V. CONCLUSIONS

In general, all three of the VAS retrieval sets produce similar temperature bias patterns when compared to the rawinsonde data. The bias patterns alternate between warm and cold in the vertical and are centered around the level of major inversions. Systematic moisture biases are prominent in both of the physical retrieval data sets while the regression scheme produces bland but relatively unbiased moisture products. The magnitude of the temperature and moisture biases vary with time and to some degree with analysis scheme. This suggests that two factors may control the quality of VAS soundings for a particular situation. First, the vertical structure of the atmosphere is a major factor for biases in the retrievals. Second, a particular retrieval scheme might produce soundings which are less biased than others for a predetermined atmospheric structure. It is not apparent, however, that any one scheme consistently produces better results in the grid mean.

Horizontal analyses presented indicate success in deriving geopotential height fields at a single time and level. Other analyses show less consistency in space and with time and the horizontal gradients are generally weaker than those of the rawinsonde observations. The 6 March 1982 experiment day is just one type of situation in which VAS soundings have been evaluated in detail. Results may or may not be the same if VAS soundings are evaluated for a different synoptic situation.

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16. ABSTRACT

Three mesoscale sounding data sets from the VISSR Atmospheric Sounder (VAS) produced using different retrieval techniques have been evaluated using corresponding ground truth rawinsonde data for 6-7 March 1982. Mean, standard deviations, and RMS differences between the satellite and rawinsonde parameters were calculated over gridded fields in central Texas and Oklahoma. Despite procedures to reduce known time and space discrepancies, large differences exist between each satellite data set and the ground truth data. Biases in the satellite temperature and moisture profiles seem extremely dependent upon the 3-dimensional structure of the atmosphere and range from 1° to 3°C for temperature and 3° to 6°C for dewpoint temperature. Atmospheric gradients of basic and derived parameters determined from the VAS data sets produced an adequate representation of the mesoscale environment but their magnitudes were often reduced by 30 to 50 percent.

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